Modeling Multiple HF Antennas on the C-130/Hercules Aircraft – Part II

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Abstract

Long-range transport aircraft such as the C-130/Hercules require reliable HF communication systems for their global missions. In some cases dual HF systems are installed using two separate antennas, in a SIMOP mode: one antenna for transmitting and the other for receiving, at arbitrary frequencies over the 2-30 MHz HF frequency range. Candidate antennas for such HF systems are probes on the vertical stabilizer or the wingtips and dorsal or wing-root notch antennas. Previous work has modeled the HF performance of these antennas by executing spectral sweeps of models at 0.1 MHz increments using the NEC4 and MBC computer codes. These results were also correlated with scale model radiation pattern and impedance measurements. In this paper the results of explicit modeling of the SIMOP mode are presented for the candidate antenna pairs. The receive antenna terminals are terminated in 50 ohms and transmit and receive currents are extracted from the solution file and each pair is plotted vs. frequency. It is seen that peaks in the antenna coupling correspond to the resonant peaks in plots of impedance reported earlier. Insights provided by current distribution plots on the wire-grid model for each antenna allow the degree of antenna coupling to be well understood. This exceptional use of the "CEM Virtual Antenna Range" can lead to very cost-effective HF SIMOP installation designs.

1.0 INTRODUCTION

The intensive international aid after the recent tragic tsunami crisis in Asia has seen the vital role of long-range transport aircraft. Amongst these, the C-130/Hercules continues to be a transportation work horse for a variety of domestic and international missions. It is a four-engine high wing STOL aircraft with distinctly large wings, a huge vertical stabilizer, and a swept tail-cone profile suited for its large cargo doors. The current configuration, labelled the C-130J, is likely to extend its lifetime for a few decades. Fig. 1 shows a United Kingdom version of the aircraft with its prominent "dorsal notch" antenna.

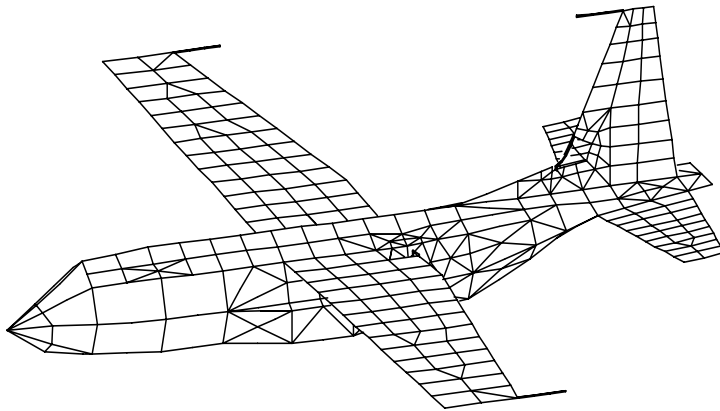**Figure 1 - Model of the C-130J with Dorsal Notch Antenna.**

The HF radio, operating over the 2-30MHz band, plays an important role in long distance radio communications, especially in global scenarios. In addition, many aircraft have been equipped with HF Near Vertical Ionospheric Sounding Capability (NVIS), for short range operation at low altitudes over hilly terrain. It is important, for all these uses, to have essential technical data that would allow the prediction and analysis of the performance of this communications system.

The EMC Laboratory first modelled the C-130 for NAWCAD in its multi-HF antenna configuration labelled the EC-130/TACAMO [1]. Subsequently the HF antenna coupling modes on the EC-130 were analyzed using NEC4 [2]. More recently, the Canadian DND C-130/Hercules was modernized to include the dorsal notch antenna shown in Figure 1. A 933 wire segment model was used to analyze the performance of this antenna [3] with NEC4. The results of the latter analysis are significant because they compared the numerical model results with measurements carried out by Lockheed-Marietta in their initial development program for the dorsal notch. In the same paper, some limited comparisons were also made with results using the MBC Galerkin code [4].
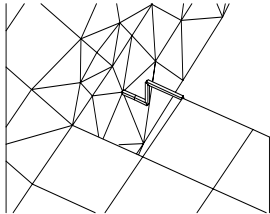
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For flexibility and reliability of HF communications, dual HF systems are often considered. These are used in the SIMOP mode. As its acronym implies, this involves the simultaneous HF transmission and reception on two distinct antennas. Apart from wire antennas, the candidate antennas are probes added to the vertical stabilizer and the wing tips, and dorsal and wing-notch antennas. With multiple antennas, the primary questions are: first, the individual antenna HF communications performance, and then the assessment of the interaction of the antennas in the SIMOP mode. Of concern is the closeness in transmit frequency that can be tolerated on one system, without causing destructive interference to the other in receive mode.

In Part I of this paper [5], the 933 segment C-130/Hercules model was modified by the addition of wing tip probes and wing-root notch and of a tail probe antenna as shown in Fig. 2. The probe antennas are modelled by adding a two meter wire onto the vertical stabilizer and the wingtips. Each is divided into three segments. The wing notch is a smaller version of the dorsal notch antenna that is adapted to the original wire grid pattern of the wing as shown in Fig. 2 b). As is customary, the models are considered to be in free space and the radiation patterns, impedance and HF performance parameters[1] are computed over the 2 to 30 MHz HF frequency range in 0.1MHz increments.

Fig. 2 a) The 1002 Segment SIMOP Model of C-130/Hercules.

Fig. 2 b) Wing Root Notch Detail.

The model was verified with the CHECK [6] software for conformance to known modeling guidelines for NEC. Models such as these have been shown to have sufficient bandwidth to produce credible results through the four-octave HF frequency range [7]. The model was executed with NEC4 and the MBC code at 0.1MHz increments with each of the HF antennas excited in turn. Recall that the EMC Laboratory Software system [8] allows us to access the solution file and process it for the display of radiation patterns, impedance, the HF Performance Parameters and the computed current distributions on the model.

From the comparative HF performance analysis plots presented in the ACES 2004 paper, it can be seen that the Dorsal Notch and Tail Probe are clearly superior to the other antennas.

2.0 EXPLICIT MODELING OF HF SIMOP OPERATION OF ANTENNAS

For HF SIMOP, one of the other antennas with lesser overall performance might be selected due to simpler installation factors. To explicitly model the SIMOP operation, the element loading feature of NEC4 was used to load the receiving antenna with 50 ohms. Then the solution files were accessed to retrieve and plot the currents at the terminals of the transmitting and receiving antenna pairs: Dorsal Notch/Tail Probe, Dorsal Notch/Wing Probe, Dorsal Notch/Wing Root Notch, Tail Probe/Wing Probe, Tail Probe/Wing Root Notch and Wing Probe/Wing Root Notch. The results for the Tail Probe/Wing Probe pair are shown below together with the impedance data for these paired antennas.

2.1 Transmit and Receive Antenna Currents in HF SIMOP Operation

Plots of computed currents vs. frequency for the Tail Probe/Wing Probe are shown in Fig. 3. The computed impedances vs. frequency (from both computer codes) are shown alongside.

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[1] The HF performance parameters are radiation pattern efficiency, %E-theta and sub-%E-theta, and NVIS (or HVIS) and are defined in references [1] and [2].
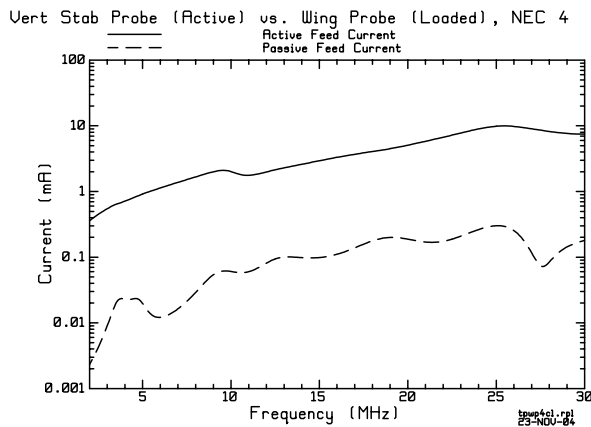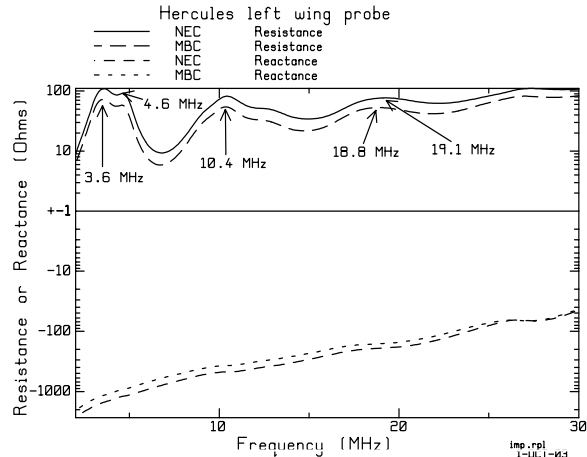
Fig. 3 a) – T/R Currents.

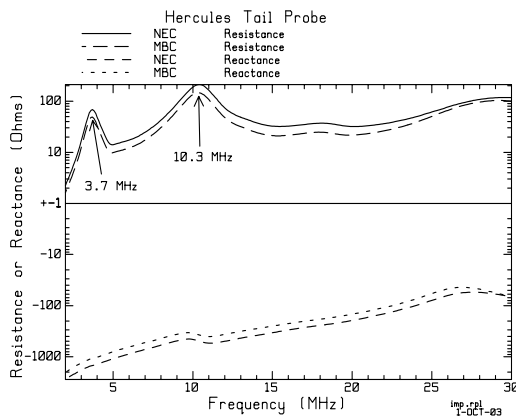**Fig. 3 b) – Impedance, Left Wing Probe.**

Fig. 3 c) Impedance, Tail Probe.

In Fig. 3a) the transmit current plot corresponds to the current from 1 volt excitation at the transmit antenna terminals. In practice an HF antenna coupler would connect the transmitter to the antenna. The receive antenna current is that at the receive antenna terminal which had been loaded with 50 ohms corresponding to the receiver input impedance. The peaks in the receive antenna current are of particular interest since they would determine the practical frequency separation that would be permitted.

It is of particular interest that these peaks coincide with the resistance peaks that are shown in Figs. 3 b) and 3 c) and correspond to common coupling to aircraft resonant modes [5]. 'A priori' knowledge of these coupling coefficients would greatly simplify the actual aircraft system design and testing. The coupling is understood from plots of the current distribution on the aircraft for each antenna.

2.2 Current Distributions Resulting in Antenna/Antenna Coupling

Current distributions at 3.7 MHz are shown in Figure 4 a) and Figure 4 b) respectively for the Tail Probe and Wing Probe antennas.
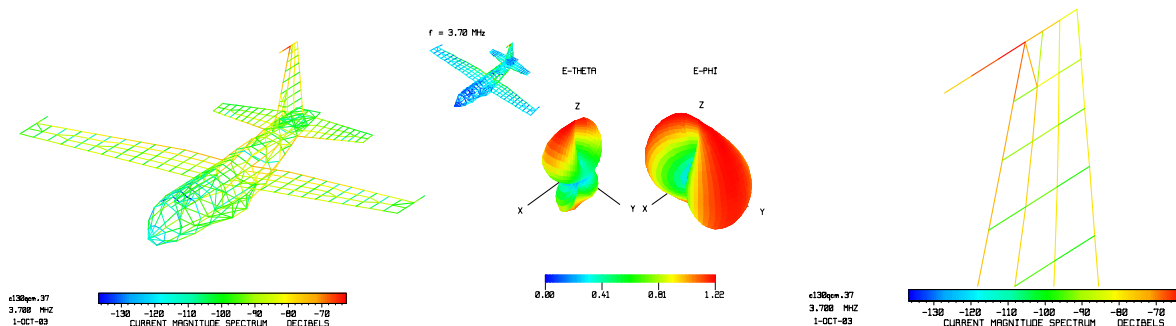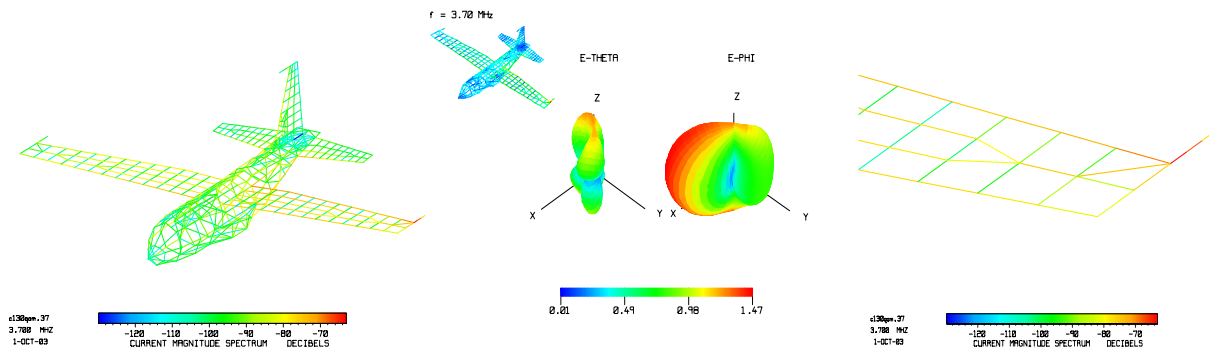

Fig. 4 a) Tail Probe – Currents and Radiation Patterns (MBC) – 3.7 MHz.

Fig. 4 b) Wing Probe – Currents and Radiation Patterns (MBC) – 3.7 MHz.

In the oral presentation, AVI movie plots of current distributions on the entire model and 3-D radiation patterns will more clearly illustrate this coupling behaviour. Also resonance bandwidth considerations are more readily evident and understood from such well illustrated frequency sweeps.

3.0 COMMENTARY

Readers are reminded that HF transmit systems can operate at power levels up to 1 kW while their receivers have sensitivities in the order of microvolts. Thus the isolation between systems is paramount for SIMOP operation. Any required selective filtering or restriction on frequency spacing for SIMOP operation must be based on detailed tests on the actual aircraft. It can be seen that having the insights provided by the above data would greatly accelerate the process of designing satisfactory systems. Thus the reliable computational modeling of the multiple HF Antenna system on the aircraft can provide clear insights into performance expectations on the actual aircraft. This "CEM Virtual Antenna Range" is worthy of exploitation and continuing verification on new aircraft designs.

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